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DO BANK CAPITAL REQUIREMENTS AMPLIFY BUSINESS CYCLES? BRIDGING THE GAP BETWEEN THEORY AND EMPIRICS

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In this paper we study the role of bank capital adequacy requirements in the transmission of aggregate productivity shocks. We identify a gap between the empirical and the theoretical work that studies the "credit crunch" effects of these requirements, and how they can work as a financial accelerator that amplifies business cycles. This gap arises because the empirical work faces some difficulties in identifying the effects of capital requirements, whereas the theory still lacks a structural framework that can address these difficulties. We bridge that gap by providing a general equilibrium theoretical framework that allows us to study this financial accelerator. The main insight we obtain is that the "credit crunch" and financial accelerator effects are rather weak, which confirms the findings of existing empirical work. Additionally, by developing a structural framework, we are able to provide an explanation for this result.

Keywords: Credit Crunch, Business Cycles, Capital Adequacy Requirements

1. INTRODUCTION

The bank capital requirements implemented with the adoption of the 1988 Basel Accords by the OECD countries have often been blamed for producing a "credit crunch." The hypothesis is that, in turn, this "credit crunch" exacerbated the recessions experienced by these countries in the early 1990s, and especially the U.S. recession of 1990–1991.[1] The idea is that the increase in capital requirements after the implementation of the Basel Accords and the drop in bank capital due to increased loan losses as these economies were entering the recessions might have forced banks to curtail their lending, which might have made the recessions worse.

We thank participants at the 2009 Latin American Meetings of the Econometric Society for helpful comments. The views expressed herein are those of the authors and do not necessarily reflect those of The Vanguard Group, Inc. Address correspondence to: María Pía Olivero, Department of Economics, LeBow College of Business, Drexel University, 503-A Matheson Hall, 3141 Chestnut St., Philadelphia, PA 19104, USA; e-mail: maria.olivero@drexel.edu.

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The empirical literature has extensively investigated whether there is enough support for this "credit crunch" hypothesis in the data. Unfortunately, this literature has not been able to reach a consensus on whether the Basel Accords were responsible for this "credit crunch" and the amplification of the recessions. The evidence is mixed. Some papers support the hypothesis [Bernanke and Lown (1991); Hancock and Wilcox (1992); Peek and Rosengren (1995a,[2] and 1995b); Sharpe (1995); Shrieves and Dahl (1995); Pazarbasioglu (1996); Vihriala (1996); Jacques and Nigro (1997); Ogawa and Kitasaka (2000); Ito and Sasaki (2002),[3] and Gambacorta and Mistrulli (2004)]. Meanwhile, other work finds no evidence for this regulation having forced banks to reduce their supply of credit [Haubrich and Wachtel (1993); Berger and Udell (1994); Hancock, Laing, and Wilcox (1995); Song (1998); Woo (1999)]. Also, descriptive statistics for G-10 countries provided by Jackson et al. (1999) show that in response to the regulation, these countries augmented their capital ratios by raising capital or substituting toward low risk-weighted asset categories, while reducing lending only in some specific circumstances.

To summarize, the "credit crunch" hypothesis does not find enough support in the data. Skeptics argue that weak loan growth merely reflected the normal procyclical pattern of both loan demand and the creditworthiness of borrowers [Peek and Rosengren (1995b)].

In general, this empirical work lacks a structural model of banks' behavior, and the approach is to run reduced-form regressions of bank lending growth on capital-to-assets ratios plus other controls for a cross section of banks. Then a positive coefficient on bank capital is interpreted as evidence for a "credit crunch." Therefore, this approach faces some difficulties in determining whether the observed slow credit growth is a demand or a supply phenomenon, and has also been criticized for interpreting correlation as causality.[4] Regarding the part of this literature, which does estimate dynamic models of bank behavior, its measures of capital adequacy cannot differentiate between endogenous changes to bank capital and changes induced by the capital regulation.

With these shortcomings and not being able to reach a consensus on the "credit crunch" hypothesis, this empirical literature faces some difficulties in studying how the impact of capital adequacy regulations on bank lending can affect macroeconomic outcomes and work as a financial accelerator that amplifies business cycles.

On the other hand, the theoretical literature on the role of capital adequacy regulations is mostly based on partial equilibrium models, where macroeconomic activity follows an exogenous process [see Peek and Rosengren (1995b), Thakor (1996), Furfine (2001), and van den Heuvel (2007), among others].[5,6] Therefore, although they can study the impact of capital requirements on banks' behavior and the "credit crunch," they cannot address the question of whether the crunch can work to amplify business cycles.[7,8] Two general equilibrium elements are crucial for that to potentially happen. First, the demand for bank credit must change *endogenously* with economic conditions. Second, in the model investment and production for bank-dependent firms must be endogenous to the supply of bank credit, so that bank credit can independently drive business cycles. Therefore, the lack of a general equilibrium theoretical foundation for the existing empirical work represents an important gap in the literature.

Our goal in this paper is to bridge this gap between empirics and theory. We do so by providing a general equilibrium theory of banks behavior as a foundation for the empirical work.[9] The contribution is twofold: First, having a structural, theoretical model of the credit crunch allows us to isolate the effect of capital requirements on bank lending, addressing the concerns raised by previous empirical work. Second, our framework allows us to study the financial accelerator effect of capital requirements.

The main insight we obtain from our general equilibrium analysis is that bank capital requirements do cause a "credit crunch," acting as a financial accelerator. After an adverse aggregate TFP shock, macroeconomic variables display more amplitude than in a no-regulation environment. The intuition is that after an adverse aggregate shock, bank profitability declines, bank equity decreases, and banks must cut back on the supply of credit to be able to meet the minimum required capital-to-assets ratio imposed by the regulation. This indirect effect of the shock working through the supply of bank credit amplifies its direct effect on the demand for credit, investment, and production. Nevertheless, the magnitude of the accelerator is small.

Thus, using a framework that is free from the criticisms faced by existing empirical work, we are still able to confirm their finding that there is weak evidence supporting the "credit crunch" hypothesis.

Additionally, by developing a structural framework, we can provide an explanation for this result. Under aggregate nondiversifiable risk, banks' optimal response to an increase in capital requirements is to accumulate capital in excess of the minimum required as a buffer against future shocks. Thus, banks are rarely capital-constrained in the stochastic steady state. Thus, an increase in capital requirements leads only to a small reduction in bank loan supply, and most of the adjustment in banks' balance sheets is done through recapitalization, via retention of earnings. With the supply of credit not falling significantly with respect to a no-regulation environment and with banks restoring their buffer of capital to its normal level immediately after the shock, the financial accelerator operates just on impact and is very short-lived. Therefore, the transitional dynamics of macroeconomic variables is still determined mainly by the persistent process followed by total factor productivity, which is present in economies both with and without regulation.

Our paper builds on Flannery and Rangan (2004), whose results show that after 1994 bank capital holdings significantly exceed the regulatory minimum, challenging the common theoretical assumption in the academic banking literature that banks hold as little capital as required by the regulation. We provide a model that relaxes this assumption, allowing banks to optimally choose their capital holdings.[10] Thus, our results are in line with Flannery and Rangan (2004) and with the data showing that the average ratio of capital to assets is well above the required minimum (see Tables A.1 and A.2 in Appendix A).

The structure of the paper is as follows. The model is laid out in Section 2. Section 3 presents the results from the qualitative analysis of the model dynamics. Section 4 concludes and outlines some directions for further research. Appendix A presents some data on bank capital holdings. Appendix B presents the results of a robustness check performed on the benchmark economy. Appendix C describes the numerical method used for the solution of the model.

2. THE MODEL

In this paper we incorporate endogenous capital accumulation and production into a general equilibrium setting, with banks subject to a capital adequacy regulation. As explained above, all these features are essential for the model to endogenously produce a financial accelerator of capital adequacy regulations. We build on Aiyagari and Gertler (1998)[11] and van den Heuvel (2007).[12] Our model is also related to that in Holmstrom and Tirole (1997), where a financial intermediary subject to agency problems is constrained by its own capital in the amount of credit it can supply.

2.1. Banks

Banks are perfectly competitive. They choose their optimal dividend payout policy (Δ_t) and retention of earnings (RE_t) to maximize the present value of the expected stream of dividend payments to their owners discounted at the households' intertemporal marginal rate of substitution (q_t).[13] The choice of Δ_t and RE_t pins down the optimal plans for equity (e_{t+1}), demand deposits (D_{t+1}), and bank loans (L_{t+1}).

As in Aiyagari and Gertler (1998) and Van den Heuvel (2007), one important assumption is that there is no issuance of bank shares ($s_t = \bar{s}$, where s_t is the stock of bank shares).[14] This assumption, however, does not mean that banks have no control over their equity. Banks can still decide on capitalization via retention of earnings.

The representative bank's optimization problem can be formulated as follows:

$$\max_{\{\Delta_t,\mathrm{RE}_t\}} E_0 \sum_{t=0}^{\infty} \prod_{j=0}^{t} q_j \Delta_t, \qquad q_j = \beta \frac{u_c(c_j, l_j)}{u_c(c_{j-1}, l_{j-1})}, \qquad q_0 = 1,$$

s.t.

$$(1-\tau)(i_t L_t + \pi_t^{\mathrm{firm}} - r_t D_t) = \Delta_t + \mathrm{RE}_t, \tag{1}$$

$$e_{t+1} = \mathrm{RE}_t + e_t, \tag{2}$$

$$L_{t+1} = D_{t+1} + e_{t+1}, \tag{3}$$

$$\Delta_t \geq 0, \tag{4}$$

$$e_{t+1} \geq \gamma L_{t+1}. \tag{5}$$

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Equation (1) defines the cash flow for the representative bank. The bank is subject to a corporate income tax with tax rate τ and with interest payments on deposits being exempt, which in turn determines a tax advantage of using debt rather than equity to finance loans. Profit-maximizing banks balance this benefit against the cost related to the capital regulation of using more debt and less equity. The introduction of this tax guarantees that the bank problem is stationary and that the financial structure does not drift toward an all-equity financing steady state [see Aiyagari and Gertler (1998)]. Because by assumption firms only source of financing is bank lending, the bank is the only claim holder of the firm and thus it earns the firm's profits (π^{firm}). The bank also receives interest income from outstanding loans ($i_t L_t$), makes interest payments on outstanding deposits ($r_t D_t$), pays dividends (Δ_t), and retains earnings (RE_t). Equation (2) is the law of motion for bank equity. Equation (3) is the bank's balance sheet constraint. The nonnegativity constraint on dividends in equation (4) can be viewed as an upper limit on retained earnings. Negative dividends would in fact operate as if the bank issued equity, so the nonnegativity constraint on dividends is introduced to eliminate this possibility.

Finally, equation (5) introduces the regulation, which indicates that at least a fraction γ of bank lending has to be financed with the bank's own equity. The presence of this constraint breaks down the Modigliani–Miller theorem for the bank, allowing real shocks that undermine the bank's capital position to affect its lending behavior.[15]

The bank's budget constraint can be obtained by combining the equality restrictions in (1)–(3):

$$\Delta_t = [1 + (1-\tau)i_t]L_t - [1 + (1-\tau)r_t]D_t - L_{t+1} + D_{t+1} + (1-\tau)\pi_t^{\text{firm}}. \quad \textbf{(6)}$$

The following FOCs are derived by solving this dynamic programming problem:

$$\Delta_t \eta_t = 0, \quad \textbf{(7)}$$

$$[(1-\gamma)L_{t+1} - D_{t+1}]\,\mu_t = 0, \quad \textbf{(8)}$$

$$(1+\eta_t) - (1-\gamma)\mu_t = E_t\{[(1-\tau)(1+i_{t+1}) + \tau][q_{t+1}(1+\eta_{t+1})]\}, \quad \textbf{(9)}$$

$$(1+\eta_t) - \mu_t = E_t\{[(1-\tau)(1+r_{t+1}) + \tau][q_{t+1}(1+\eta_{t+1})]\}, \quad \textbf{(10)}$$

where η_t and μ_t are the shadow values corresponding to the dividends and regulatory constraints, respectively.

Equations (7) and (8) are the complementarity conditions for the two constraints. The Euler equations (9) and (10) describe the optimal intertemporal decisions of the bank as regards loans and deposits, respectively.

Subtracting (10) from (9), we get the following expression governing the bank's interest rate spread:

$$\gamma \mu_t = E_t\{(1-\tau)(i_{t+1} - r_{t+1})[q_{t+1}(1+\eta_{t+1})]\}. \quad \textbf{(11)}$$

It is clear from equation (11) that the existence of the capital regulation makes banking costly and results in a positive interest rate spread. With no regulation ($\gamma = 0$), the spread would be zero. Another condition for a positive spread is that the capital requirement binds (i.e., $\mu > 0$). The intuition is that when the capital requirement is not binding, banks can overcome the tax disadvantage of regulatory capital without charging a spread, by shifting the full burden of the corporate tax to their stockholders (i.e., by reducing dividend payments in the amount of the tax).[16]

It will also become clear later that the spread is countercyclical, along the lines of the empirical evidence provided by Aliaga-Díaz and Olivero (2010) and Olivero (2010).

2.2. Households

The representative household in the economy maximizes its lifetime utility by choosing the optimal lifetime profile of consumption (c_t), labor (l_t), bank deposits (D_{t+1}), and bank shares (s_{t+1}) priced at p_t. Households also have access to a storage technology (Z_{t+1}) that pays no return and that provides no service to households, other than being an alternative way to smooth consumption. This asset is introduced into the model to prevent the interest rate on deposits from becoming negative in equilibrium. After a negative shock that makes the bank hit the regulatory constraint, the return on bank shares might become negative. By arbitrage, r might become negative too, as banks lower their demand for deposits. However, with households having access to this substitute technology that pays a zero return, banks are not allowed to lower the interest rate on deposits below zero.

Therefore, the representative household optimization problem is given by

$$\max_{\{c_t, l_t, D_{t+1}, s_{t+1}, Z_{t+1}\}} E_0 \sum_{t=0}^{\infty} \beta^t \left[u(c_t, l_t)\right],$$

s.t.

$$(1 + r_t)D_t + Z_t + w_t l_t + \left[\frac{\Delta_t}{s_t} + p_t\right] s_t + \mathrm{TR}_t \geq c_t + D_{t+1} + p_t s_{t+1} + Z_{t+1}, \quad (12)$$

$$Z_t \geq 0. \quad (13)$$

The flow budget constraint in equation (12) indicates that the household income is made up of interest payments from deposits, Z holdings of the storage asset from the previous period, wages, bank dividends, the value of bank shares, and a lump-sum government transfer (TR_t), financed with the corporate income tax paid by banks.

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The FOCs for this dynamic problem are

$$-\frac{u_l(c_t, l_t)}{u_c(c_t, l_t)} = w_t, \tag{14}$$

$$u_c(c_t, l_t) = \beta E_t\{(1 + r_{t+1})[u_c(c_{t+1}, l_{t+1})]\}, \tag{15}$$

$$u_c(c_t, l_t) = \beta E_t \left[u_c(c_{t+1}, l_{t+1}) \left(\frac{p_{t+1} + \frac{\Delta_{t+1}}{s_{t+1}}}{p_t} \right) \right], \tag{16}$$

$$u_c(c_t, l_t) \geq \beta E_t[u_c(c_{t+1}, l_{t+1})], \quad Z_t \geq 0. \tag{17}$$

Equation (14) equates the marginal rate of substitution between consumption and leisure to the wage rate. Equations (15), (16), and (17) are the Euler conditions describing the optimal intertemporal allocation of savings to bank deposits, bank equity, and the storage technology, respectively.

2.3. Firms

Firms are perfectly competitive. The representative firm chooses the optimal level of investment (I_t), labor demand (l_t), and bank borrowing (L_{t+1}) to maximize the expected present discounted value of lifetime cash flows. The discount rate used here is the opportunity cost of funds for the firms' owners (the banks), given by the rate on deposits.

The firm's problem is represented by[17]

$$\max_{\{I_t, l_t, L_{t+1}\}} E_0 \sum_{t=0}^{\infty} \left[\prod_{j=0}^{t} \frac{1}{1 + r_j} \right] \pi_t^{\text{firm}}, \quad r_0 = 0,$$

s.t.

$$\pi_t^{\text{firm}} = A_t F(K_t, l_t) - w_t l_t - I_t + L_{t+1} - (1 + i_t) L_t, \tag{18}$$

$$K_{t+1} = I_t + (1 - \delta) K_t, \tag{19}$$

$$L_{t+1} \geq K_{t+1}, \tag{20}$$

$$\log A_{t+1} = \rho \log A_t + \epsilon_{t+1}, \quad \epsilon_{t+1} \sim N(0, \sigma^2). \tag{21}$$

Equation (18) defines firms' profits. Equation (19) gives the law of motion for the economy's capital stock (K_t).

The inequality constraint in equation (20) imposes the need for bank financing in the model. Because the interest rate on loans is always higher than or equal to the discount rate, firms prefer internal sources to external financing, and the constraint holds with equality.

More specifically, equation (20) states that net investment must be entirely financed with new debt (i.e., $L_{t+1} - L_t$), whereas capital depreciation must be paid out of the firm's cash flow.

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Also notice that if the firm is constrained to using only these one-period loans, in the special case in which there is no net investment (i.e., $I_t = \delta K_t$) and in which the capital stock is constant ($K_{t+1} = K_t$), a balance sheet argument implies that the constant stock of capital has to be financed by a combination of firm equity and short-term loans that get rolled over period by period.[18] If the firm is forbidden to hold any equity, then its capital stock must be financed solely by short-term loans that must be rolled over. Thus, equation (20) is also equivalent to restricting the firms from using equity financing, either by issuing new equity or by retaining earnings. This implicit constraint on equity financing imposed on the firms is different from the equity constraint imposed on banks, which are not allowed to issue new equity but can retain earnings. This asymmetry between the types of constraint imposed on the firms' and the banks' sides of the model is admittedly arbitrary, but a tractable way of imposing the need for debt financing in the model.[19] Moreover, the focus of our paper is not on the particular reason for the existence of bank financing in equilibrium, but on how the supply of this financing is affected by bank capital requirements.

Finally, equation (21) is the exogenous process followed by the total factor productivity (TFP, represented by the index A_t).

The FOCs arising from the dynamic problem are

$$A_t F_l(L_t, l_t) = w_t, \quad \textbf{(22)}$$

$$E_t \left\{ \frac{1}{(1 + r_{t+1})} [A_{t+1} F_K(L_{t+1}, l_{t+1}) - (\delta + i_{t+1})] \right\} = 0, \quad \textbf{(23)}$$

where, after deriving, we have substituted K with L.

Equation (22) is the static condition for optimal labor demand, and equation (23) is the Euler equation indicating the firms' optimal capital accumulation decision.

2.4. The Recursive Competitive Equilibrium

Each decision-making unit solves an independent dynamic programming problem in the decentralized recursive competitive equilibrium.

The state variables for households are $\upsilon_t^h = [D_t, Z_t, s_t, r_t, \Upsilon_t]$ where Υ_t stands for the economywide counterparts of all state variables in the model $A_t, K_t, L_t, D_t, e_t, Z_t, s_t, r_t,$ and i_t.[20] For banks and firms the states are given by $\upsilon_t^b = [D_t, L_t, e_t, r_t, i_t, \Upsilon_t]$ and $\upsilon_t^f = [A_t, K_t, L_t, i_t, r_t, \Upsilon_t]$, respectively.

The recursive competitive equilibrium in this economy is stationary and can be defined by

- The value functions for the decision-making units: $V^h(\upsilon_t^h)$, $V^b(\upsilon_t^b)$, and $V^f(\upsilon_t^f)$.
- A set of optimal decision rules: $c(\upsilon_t^h), l(\upsilon_t^h), D(\upsilon_t^h), Z(\upsilon_t^h), s(\upsilon_t^h)$ for households; $D(\upsilon_t^b)$,$L(\upsilon_t^b)$,$RE(\upsilon_t^b)$, $\Delta(\upsilon_t^b)$,$e(\upsilon_t^b)$ for banks; and $l(\upsilon_t^f)$, $I(\upsilon_t^f)$, $L(\upsilon_t^f)$ for firms.

- The corresponding set of aggregate decision rules.
- Price functions: $i(\Upsilon_t)$, $r(\Upsilon_t)$, $p(\Upsilon_t)$ for financial assets; $w(\Upsilon_t)$ for labor; and shadow prices of the constraints $\eta(\Upsilon_t)$ and $\mu(\Upsilon_t)$.

These functions satisfy

- Households', banks', and firms' intertemporal optimization conditions.
- Market clearing conditions in the markets for labor, bank deposits, bank loans, and bank shares.
- Consistency between individual and aggregate decisions.
- The households' budget constraint, the banks' budget constraint, the capital regulation constraint, the nonnegativity of dividends, the nonnegativity of Z_{t+1}, $s_{t+1} \equiv 1$, and the balance sheet condition for firms $L_{t+1} = K_{t+1}$.

3. NUMERICAL SOLUTION AND RESULTS

3.1. Numerical Solution

In this section we seek to derive the optimal response functions mapping the state space Υ_t into the agents' decisions. After $K_{t+1} = L_{t+1}$, $\text{TR}_t = \tau(i_t L_t + \pi_t^{\text{firm}} - r_t D_t)$, and $s_{t+1} \equiv 1$ are imposed the bank's budget constraint (6) is used to eliminate Δ_t, the resulting policy functions are the solution to the functional equation problem given by (7)–(10), (14)–(17), (22), and (23).

These optimal response functions cannot be obtained analytically; they have to be approximated numerically. For this purpose we use a finite-element method [see McGrattan (1999) and Fackler (2005)]. This method belongs to the more general class of weighted residual methods [Judd (1991)], where the approximation to the policy functions is done through a linear combination of known basis functions. The coefficients on the linear combination, which are the objects to be computed to obtain the approximate solution, are found by the collocation method. The nonlinear system is solved through a fixed-point iteration scheme [Fackler (2005)]. This is an alternative to generic root-finding algorithms (such as the Newton or the quasi-Newton method), with smaller computing requirements. A complete discussion of this method can be found in Fackler (2005). The Appendix includes more details on the numerical solution and an explanation of the issues that are specific to our model.

The numerical simulations of the model are used here to examine the qualitative dynamics of the system in response to exogenous shocks to γ and to TFP. The parameter values used are standard in the RBC literature, and are presented in Table 1. It is worth noting that this is a qualitative study, and it is not our goal to do a calibration exercise.

The households' utility function is of the constant relative risk aversion (CRRA) type over an aggregate of consumption and leisure. To make it possible to abstract from wealth effects on labor supply, this aggregate is assumed to be

TABLE 1. Parameter values

Parameter	Value
α	0.33
β	0.96
δ	0.1
θ	2
ω	2
ρ	0.8
σ	0.01
γ	0.08
τ	0.15

of the Greenwood, Hercowitz, and Huffman (GHH) type. Thus,

$$u(c_t, l_t) = \frac{\left(c_t - \frac{l_t^{\omega}}{\omega}\right)^{1-\theta}}{1-\theta}.$$

A Cobb–Douglas specification is assumed for the production technology: $A_t F(K_t, l_t) = A_t K_t^{\alpha} l_t^{1-\alpha}$.

The parameters values for α, β, δ, and θ are standard in the RBC literature for the U.S. postwar annual data [Prescott (1986)]. The parameter ω is set to 2, to match a unitary elasticity of labor supply.

The autocorrelation coefficient ρ and the standard deviation of TFP shocks σ are in the range of estimates from the TFP process arising from the U.S. business cycle measured at an annual frequency. The required capital-to-assets ratio γ is set to 8%, as specified in the Basel Accords of 1988, and the corporate income tax rate τ is set to 15%.

All results are robust to the choice of parameter values. Sensitivity analyses are available from the authors upon request.

3.2. Results

In this section we use simulations of the model to address two questions. First, how do banks respond to an increase in capital requirements? (i.e., is there a "credit crunch" effect of capital requirements?) Second, can that "credit crunch" effect of capital requirements work as a financial accelerator of business cycles and, if so, how?

An increase in capital requirements and the credit crunch. Our model is able to explain why the representative bank finds it optimal to hold "excess capital," something crucial to evaluate the effect of changes in capital requirements on bank lending and macroeconomic activity.

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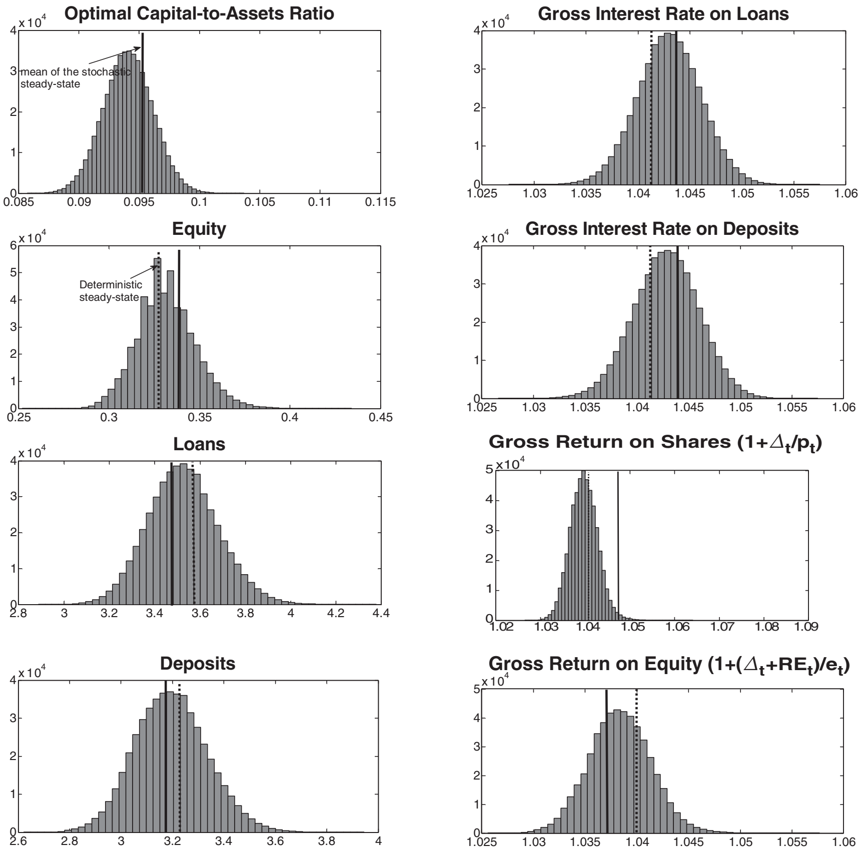

FIGURE 1. Stationary distribution of bank variables.

The capital regulation operates as a restriction on net asset holdings [i.e., $(1 - \gamma)L_t - D_t \geq 0$]. In the context of aggregate uncertainty, this restriction results in banks having to acquire self-insurance.[21] They do so by overaccumulating capital above the regulatory limit. This makes sense: the bank desires a buffer of equity.

Figure 1 shows the stationary distribution of several variables related to the bank's problem, and computed from 500 simulations of length 1,000 each. In particular, the mean of the optimal capital-to-assets ratio over the stochastic steady state is 9.4%, well above the required minimum of 8%. Comparing the expected values of these variables (vertical solid lines) with their deterministic steady-state counterparts (vertical dashed lines), it can be seen that when faced with uncertainty, banks decide to hold more equity (and less deposits) than in a deterministic scenario. As a result, they also lend less than in the no-uncertainty case (see left-hand-side panels in Figure 1).

The level of excess capital holdings predicted by our simulations is consistent with the empirical findings in Flannery and Rangan (2004), according to which capital ratios significantly exceed the regulatory minimum. They show that the mean Tier 1 (total = Tier 1 + Tier 2) capital for the 100 largest bank holding companies in the United States stood at 7.26% (9.44%) of risk-weighted assets in 1986, increased considerably to 11.1% (13.8%) by 1994, and remained stable after then. Our average holdings of 9.4% (see Figure 1) are in line with the data for U.S. banks in 2000 presented by Van den Heuvel (2008), and with the average of 8.8% from Bankscope data (see Table A.1). However, both the average 9.5% and even the largest ratio that our model delivers (10.4%) fall short of the recent data from the IMF Global Financial Stability Report, according to which equity as a percentage of risk-weighted assets is approximately 11% for the developed world. The fact that the buffer that we obtain is smaller than the IMF data calculated using risk-weighted assets is in part related to the absence of a role for risk weights in our model.[22] Notice that the IMF data show even larger buffers for emerging economies (in the range of 15%) (see Table A.2). Our general equilibrium model, for which the size of the buffer itself is endogenous, could reproduce these high buffers for a higher volatility of the aggregate productivity shock. This seems a reasonable assumption for these emerging economies.

In our model it is clear from the representative bank's Euler equations that when deciding on the optimal level of debt financing, the bank balances its benefit (debt financing is tax-exempt) against its cost (higher debt implies a higher probability of hitting the capital constraint, and thus a higher probability of the non-negativity constraint on dividends binding next period and a higher shadow price $E_t[\eta_{t+1}] > 0$).

The bank, however, does not resort to an all-equity financing strategy because in equilibrium the return on equity obtained by the bank falls short of the cost of funds (which is approximately equal to $(1 + r) = 1.04$ in the deterministic steady-state). This is shown in Figure 1 by the gap between the solid and dashed lines in the plot for the gross returns on equity $[1 + (\Delta_t + \mathrm{RE}_t)/e_t]$ and for the gross interest rate on deposits. Note that a return on equity lower than $(1 + r)$ is consistent with a risk premium on bank shares (see the plot for the gross returns on bank shares $[1 + (\Delta_t/p_t)]$. Given that bank deposits are risk-free, risk-averse households will hold bank shares only if they are compensated for risk.

Note that in the simulations the excess capital is large enough for the probability of a binding regulation constraint to be very small. The explanation for this is that for a lower level of excess capital (i.e., one in which the probability of hitting the constraint is positive) it is not guaranteed that the bank will be able to meet the regulatory constraint in every state of nature. The reason is that it is net investment that is financed with new lending $(L_{t+1} - L_t)$, which implies that the largest reduction in bank lending is limited to $-\delta K_t$ (i.e., zero gross investment). Thus, when equity falls after a negative shock, the bank first attempts to recapitalize via retention of earnings. If equity falls enough, dividends eventually fall to zero and the bank must start cutting back on lending in order to

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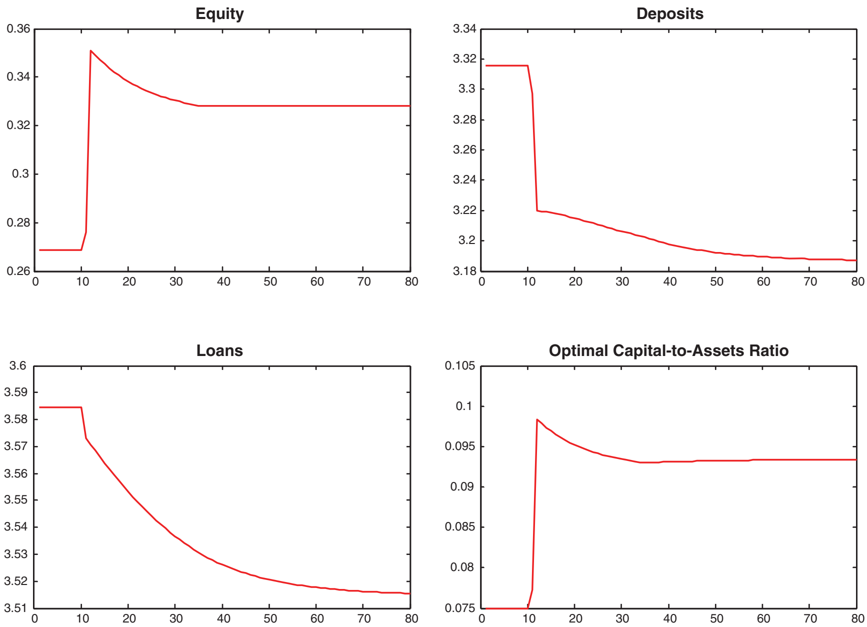

FIGURE 2A. Transitional dynamics for a permanent change in γ from $\gamma = 0.06$ to $\gamma = 0.08$: Bank variables.

meet the minimum requirement. However, the bank is also limited in the amount by which it can reduce lending. Therefore, in some states of nature the constraint will not be met. The bank builds up enough excess capital to prevent this from happening.

A second issue that is crucial for the evaluation of the "credit crunch" hypothesis is to understand how banks respond to an increase in capital requirements. Do they increase equity, do they cut back on lending, or both?

Figures 2A–2C show the expected path followed by banks, as well as macroeconomic variables, after an unexpected and permanent change in the required ratio from 6% to 8% (i.e., these figures show the transitional dynamics of the model from a low-γ to a high-γ steady state).[23] These values roughly resemble the change in capital regulation that occurred in the United States between 1990 and 1992: The United States had implemented solvency regulations since 1981, setting the legal minimum to 6%. After the adoption of the Basel Committee standards, the ratio was increased to 8%. The simulations were performed by setting starting values of the variables at the mean of the stochastic steady state corresponding to $\gamma = 0.06$ and introducing the policy change in period 10 of the simulations.

The increase in γ squeezes the excess capital on impact, which makes both the dividends and the regulatory constraints bind (see the plots for the shadow value of both constraints in Figure 2B). Banks respond by raising the optimal

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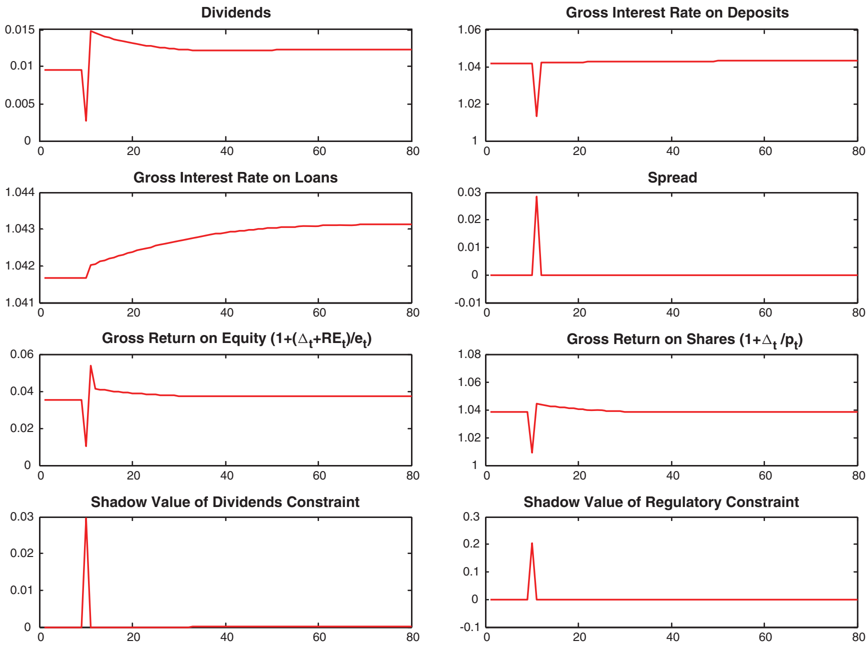

FIGURE 2B. Transitional dynamics for a permanent change in γ from $\gamma = 0.06$ to $\gamma = 0.08$: Bank variables.

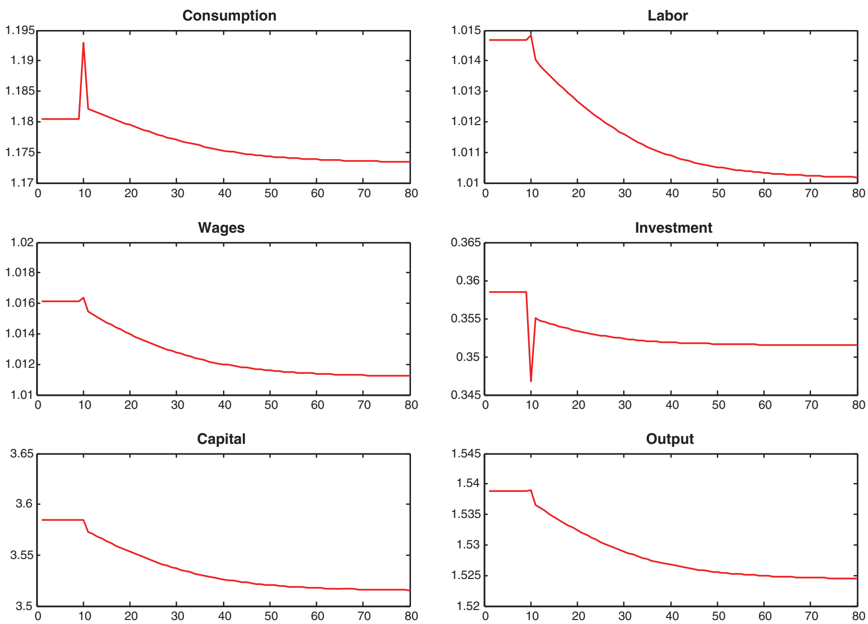

FIGURE 2C. Transitional dynamics for a permanent change in γ from $\gamma = 0.06$ to $\gamma = 0.08$: Macroeconomic variables.

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capital-to-assets ratio from around 7.5% to 9.4%. This response is given mainly by an increase in equity holdings. Banks retain earnings until the higher level of equity is reached. That is, both equity and dividends increase over the long run, but dividends fall on impact as retained earnings increase enough. It can be seen there that the bank finances the excess equity holdings by paying a lower return on them. Also, the gross return on shares falls by arbitrage.

It is interesting to compare the dynamics in the capital ratio to those in Flannery and Rangan (2006). Even though this paper deals with nonfinancial firms, it presents an appropriate framework for studying the adjustment of banks' capital toward their target. They show that the typical firm closes about one-third of the gap between its actual and its target debt ratios each year. In our case, the adjustment toward the new steady state level of capital happens in 20 years; i.e., the average bank closes an average of 5% of the gap each year (see Figure 2A). This result implies an adjustment speed that is significantly lower than in Flannery and Rangan (2006) and closer in magnitude to the previous work on capital structure cited therein.

In this general equilibrium analysis, when banks retain earnings and lower dividend payments, the interest rate on deposits falls by arbitrage. As the interest rate on deposits falls, demand deposits fall by more than the increase in equity (in absolute value), and banks have to cut back on lending.[24] That is, bank loans are also affected by the increase in the capital requirements. They fall, although not significantly.

This result has not been obtained before, and it allows us to learn something about the effects of capital requirements that previous work is silent about. That is, the standard view in both previous theoretical work and informal analyses is that banks cut back on lending only when the capital regulation becomes binding [Blum and Hellwig (1995); Aiyagari and Gertler (1998); Van den Heuvel (2007)]. However, according to our results, part of the percentage increase in the optimal capital-to-assets ratio is due to a reduction in lending, even when the capital-to-assets ratio is well above the minimum required. This conclusion deserves greater emphasis in the current bank capital policy debate, which mostly focuses on a framework of binding capital requirements.

These results have direct implications for the hypothesis that the increase in bank capital requirements in 1988 caused the "credit crunch" of the early 1990s. The findings in the empirical literature are mixed and in general provide weak support for this hypothesis. The simulations from our structural model shown in Figures 2A–2C seem to confirm those findings, even when they are free from the critiques made of empirical work.[25] They show that banks do cut back on lending after the change in capital requirements. Only 3% of the percentage increase in the capital-to-assets ratio is due to a reduction in lending (97% is due to a change in banks' retained earnings). As a result, the interest rate increases very little in the long run.

Worth noting is that the small effect on the supply of loans does not mean that capital adequacy regulation plays no role during an economic downturn. The stringency of bank capital requirements may well still influence the dynamics of macroeconomic variables as the economy heads toward a recession. We investigate this link in the next section.

Figure 2C plots the transitional dynamics of macroeconomic variables from the low-γ to the high-γ steady state. It shows a jump in consumption as the interest rate on deposits falls. The increase in bank spreads and interest rates on loans drives up the cost of credit and lowers investment.[26] The stock of capital falls as capital accumulation slows down, and the marginal productivity of labor is negatively affected. As a result, employment, wages, and output all fall as the system moves to the new steady state. Worthy of note is the reduction in output by approximately 1%.

The fact that the new steady-state level of consumption is 99.6% of the level when $\gamma = 0.06$ indicates that the welfare cost of capital requirements in our model is rather small. This is different from the conclusions in Van den Heuvel (2008). In the next section we explore the reason for the difference in results.

A financial accelerator of business cycles. In this section the model is used to explore the extent to which bank capital requirements can work as an automatic amplifier of aggregate fluctuations. This hypothesis has not been studied before in the context of a structural DSGE model.

As a first step, we analyze the economy's response to a negative TFP shock under a no-regulation scenario (i.e., $\gamma = 0$). Then we compare the dynamic paths in this economy to those of a regulated economy.

When there are no capital requirements, due to the tax exemption on deposits, banks will choose to hold no equity. With no equity and thus no dividend payments, inequality constraints (4) and (5) become irrelevant to the problem. Therefore, the model collapses to a standard closed-economy RBC model with firms making investment and production decisions and households making consumption–saving decisions. Banks are completely redundant in this setting, and because they are perfectly competitive, the interest rate spread is zero.

As usual in standard RBC models, after a negative TFP shock, the interest rate falls (following the reduction in the marginal product of capital and in firms' demand for credit). The responses of output, consumption, labor, and investment are all the expected ones. They are all positively linked to TFP, the only source of fluctuations in the model.

Figure 3 displays banks' optimal responses in the regulated environment derived by perturbing the system with a TFP shock big enough to make the capital requirement bind (see bottom left panel). Bank equity falls (see top right panel). The intuition for this drop in equity is the following: Firms' profits (π_t^{firm}) fall after a negative TFP shock. With the banks being the only claim-holders to the firm (by $K_{t+1} = L_{t+1}$), firms' profits are rebated to the banks. Therefore, the fall in profits has a negative impact on banks' retained earnings and profitability, so that bank equity falls [see the relationship between earnings and equity described by equation (2)].[27]

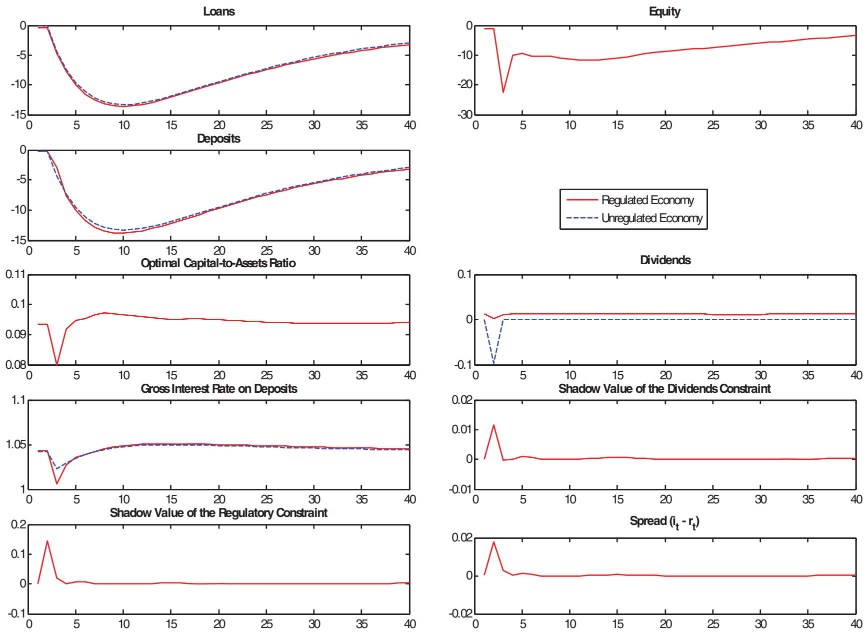

FIGURE 3. Impulse-response functions for bank variables to a negative TFP shock that makes the CA regulation bind. Values on the vertical axes are percentage deviations with respect to the steady state for loans, equity, and deposits. They are levels for all other variables.

Having firms' profits rebated to banks allows us to have creditors be affected by a negative shock to borrowers' balance sheets in a reduced-form way, without the need to explicitly model increased borrowers' default during economic downturns. We are using this short cut because modeling borrowers' default from first principles is beyond the scope of our paper, where we want to focus on the role of frictions on the lenders side of the market. Moreover, it would unnecessarily complicate the model and compromise its numerical tractability without adding any new insights into the financial accelerator role of bank capital requirements as an amplifier of TFP shocks. Also, the assumption that π_t^{firm} is rebated to the banks (so that when borrowers' profits fall in recessions, banks see their own income falling too) is equivalent to having an exogenous write-off rate of loans in the bank's cash flow equation, as in equation (1) of Van den Heuvel (2007).

If capital-to-assets ratios fall below the regulatory minimum as a result of this reduction in equity, banks find themselves needing to recapitalize. They do so by retaining earnings up to the point where the constraint on dividends becomes binding. After this, further adjustments to the capital-to-assets ratio have to be achieved by curtailing the supply of loans. Thus, credit availability is restricted in the model relative to a standard model that lacks capital requirements. This induces borrowers to further lower employment and investment, which amplifies the

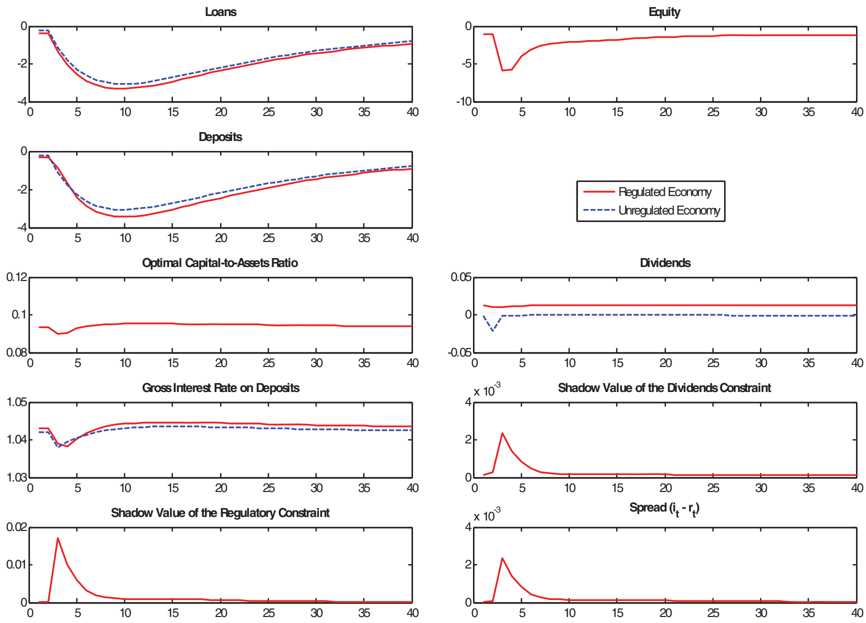

FIGURE 4A. Impulse-response functions to a −2.5% TFP shock: Bank variables. Values on the vertical axes are percentage deviations with respect to the steady state for loans, equity, and deposits. They are levels for all other variables.

standard effects of a negative TFP shock, making the recession deeper and longer. Furthermore, the higher the required capital (i.e., the larger γ), the more likely it is that the dividends constraint binds in downturns, the more likely that a bank will need to cut its loan supply, and therefore the stronger the financial accelerator.

Now there is an additional effect of the shock on the supply of credit operating together with its direct effect on the demand for credit. This is how the regulation works to amplify business cycles. Banks respond as expected during the recession. As shown by the second subplot on the right-hand side, they first cut dividend payments and retain earnings as a way to recapitalize, and in an attempt to avoid cutting back on loans. However, eventually either the nonnegativity constraint on dividends is hit or the marginal utility on dividends goes up so that banks prefer to reduce credit, and deposits fall too (see first two plots on the left). In any case, with the regulation binding ($\mu_t > 0$), and with banks cutting lending, the interest rate spread increases (see bottom right panel),[28] and the interest rate on deposits decreases by more than in the no-regulation case.

Notice that the responses of both loans and deposits are slightly larger in the regulated economy than in the economy with $\gamma = 0$, which provides weak evidence for the "credit crunch" hypothesis.

The fact that such a big shock is needed for the constraints to bind is consistent with the stationary distributions shown in Figure 1. In those simulations the

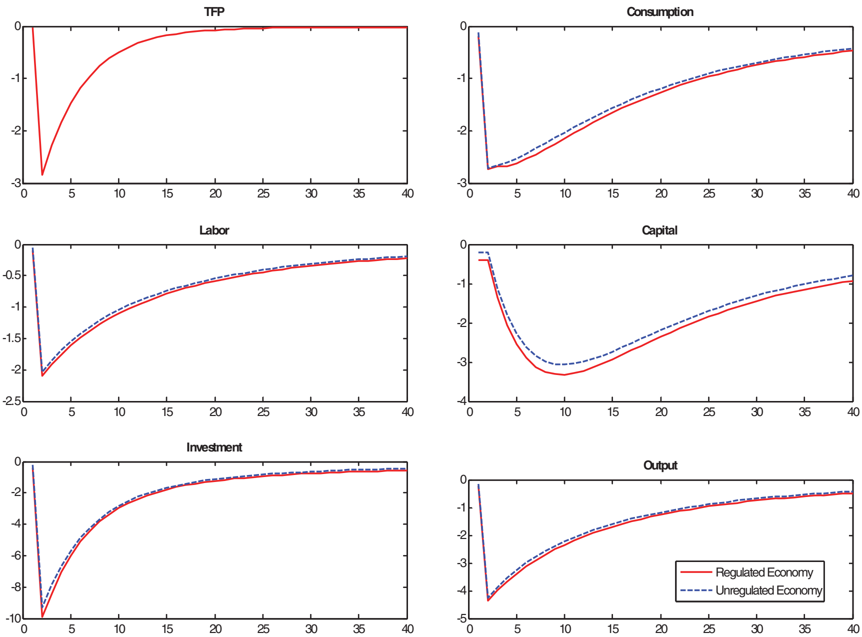

FIGURE 4B. Impulse-response functions to a -2.5% TFP shock: Macroeconomic variables. Values on the vertical axes are percentage deviations with respect to the steady state.

probability of the constraint binding is almost zero. One could conclude from this that the financial accelerator is a mere theoretical possibility that would never arise in practice. However, it is evident from Figures 2A–2C that the constraints always reshape banks' optimal behavior. In Figures 4A and 4B we show next that the financial accelerator is at work even for shocks of moderate size.

Figure 4A shows the response of key bank variables to a negative shock of any size that reduces bank profitability, and for which the buffer of excess capital falls below the desired level, but not necessarily below γ (see third panel on the left). This is enough for banks to immediately start cutting back on loans, which amplifies the real effects arising from the reduction in the demand for credit. At the same time, banks retain earnings and reduce dividend payments. Thus, the return on bank shares falls and, by arbitrage, the interest rate on deposits also declines. As a result, demand deposits fall by more than in the nonregulation case.

Figure 4B displays the responses of macroeconomic variables to this TFP shock. Owing to the reduced demand deposits and to the fall in equity, bank loans and investment decrease more than in the economy with no regulation. After that, all macroeconomic variables remain below their no-regulation counterparts as the economy returns to its steady state. It is worth noting that on impact, output displays the same dynamics in both economies. However, over time, output starts to lag behind as the differential effect on investment builds up and the capital

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stock recovers at a slower pace. Given that the capital stock decreases one to one with bank loans, wages, employment, investment, and output all display more persistence than in the economy with no capital requirements.

Last, Table 2 shows the distribution moments obtained by simulating the model 500 times with each simulation of length 1,000. The financial accelerator caused by capital regulation is also evident from the second and third panels in this table. The standard deviations for all variables (both in absolute terms and relative to that of GDP) are greater in the economy with $\gamma > 0$.

It is clear from the dynamic response of the system that the size of the financial accelerator effect is small compared to the size of the TFP shock (see Figure 4B and standard deviations in Table 2). This result is robust across parameterizations of the model. As was described before, along the stochastic steady state, banks keep a buffer of excess capital to cushion the effect of negative aggregate shocks. An unexpectedly large shock may make equity fall enough to make the constraint bind on impact. However, immediately after the shock, banks try to restore the buffer of capital to its normal level. Thus, these banks respond to a tightening in capital requirements mainly with an increase in their equity holdings, and only slightly by cutting back on lending. As a result, the financial accelerator operates just on impact, and it is very short-lived. This is consistent with a weak "credit crunch" effect found in the simulations in the preceding section. On the other hand, the reduction in the demand for credit (which relaxes the regulation constraint) inherits the persistence of the TFP process, and it is highly persistent. This last effect operates on impact but also builds up over time.

Carlstrom and Fuerst (1997) (CF) develop a computable general equilibrium version of the model in Bernanke and Gertler (1989) (BG) *quantitatively* capturing the *qualitative* financial accelerator in BG.[29] One important difference between our and the CF financial accelerator is related to the dynamics of the response to a TFP shock. CF are able to replicate the empirical fact that output growth displays positive autocorrelation at short horizons. The reason is that in their setup the cost of credit (i.e., agency costs) is a function of borrowers' capital and net worth. Thus, investment, employment, and output display a hump shape that mimics the hump-shaped response of capital to TFP shocks. The hump in output arises because investors delay their investment decisions until the point where agency costs are at their lowest—a point in time several periods after the initial productivity shock [Carlstrom and Fuerst (1997)]. This is not true in our model, where the strongest impact on firms' cost of credit and investment takes place right after the shock. In our model, even in the presence of capital adequacy regulations on the financial sector, the dynamics of macroeconomic variables is all inherited from the autocorrelation structure of the technology shock. Using the terminology in CF, capital adds little propagation to these variables in and of itself.

Our simulated accelerator is significantly smaller than that in Bernanke et al. (1998). In a nutshell, this model is BG augmented with money and price stickiness, lags in investment and heterogeneity among firms. Their Figure 4 shows on impact a 30% difference in the impulse response of output to a productivity shock between

TABLE 2. Simulation moments: Macroeconomic variables

	Regulated economy $\gamma = 0.08$	Unregulated economy $\gamma = 0$
	Means ($\mu(x)$)	
TFP (A)	1.0001	1.0000
Capital (K_{t+1})	3.5266	3.5808
Consumption (C_t)	1.1751	1.1798
Labor (l_t)	1.0109	1.0141
Wages (w_t)	1.0120	1.0156
Investment (I_t)	0.3526	0.3581
Output (Y_t)	1.5272	1.5381
	St. dev. ($\sigma(x)$)	
TFP (A)	0.0166	0.0165
Capital (K_{t+1})	0.1508	0.1449
Consumption (C_t)	0.0364	0.0359
Labor (l_t)	0.0183	0.0178
Wages (w_t)	0.0201	0.0196
Investment (I_t)	0.0230	0.0222
Output (Y_t)	0.0578	0.0568
	St. dev. relative to output ($\frac{\sigma(x)}{\sigma(Y)}$)	
TFP (A)	0.2868	0.2904
Capital (K_{t+1})	2.6097	2.5529
Consumption (C_t)	0.6304	0.6325
Labor (l_t)	0.3159	0.3140
Wages (w_t)	0.3478	0.3459
Investment (I_t)	0.3975	0.3910
	Correlations with GDP ($\rho(x, Y)$)	
TFP (A)	0.8652	0.8754
Capital (K_{t+1})	0.8039	0.7972
Consumption (C_t)	0.9839	0.9858
Labor (l_t)	0.9999	0.9999
Wages (w_t)	0.9999	0.9999
Investment (I_t)	0.9609	0.9628
	Means ($\mu(x)$)	
Equity (e_{t+1})	0.3318	—
Deposits (D_{t+1})	3.1948	—
Gross interest rate on deposits ($1 + r_{t+1}$)	1.0428	1.0419
Spread ($i_{t+1} - r_{t+1}$)	0.0002	—
Dividends (Δ_t)	0.0127	—
	St. dev. ($\sigma(x)$)	
Equity (e_{t+1})	0.0157	—
Deposits (D_{t+1})	0.1371	—
Gross interest rate on deposits ($1 + r_{t+1}$)	0.0031	0.0028
Spread ($i_{t+1} - r_{t+1}$)	0.0005	—
Dividends (Δ_t)	0.0014	—

TABLE 2. (Continued.)

	Regulated economy $\gamma = 0.08$	Unregulated economy $\gamma = 0$
St. dev. relative to output ($\frac{\sigma(x)}{\sigma(Y)}$)		
Equity (e_{t+1})	0.2711	—
Deposits (D_{t+1})	2.3731	—
Gross interest rate on deposits ($1 + r_{t+1}$)	0.0544	0.0496
Spread ($i_{t+1} - r_{t+1}$)	0.0085	—
Dividends (Δ_t)	0.0239	—
Correlations with GDP ($\rho(x, Y)$)		
Equity (e_{t+1})	0.9026	—
Deposits (D_{t+1})	0.7807	—
Gross interest rate on deposits ($1 + r_{t+1}$)	−0.0478	−0.0602
Spread ($i_{t+1} - r_{t+1}$)	−0.4113	—
Dividends (Δ_t)	0.8880	—

the economies with and without the financial accelerator. After 12 periods the percentage difference between these two economies rises to 50%.

The capital regulation is imposed in our model and it has no social value, in the sense of reducing the moral hazard problem associated with deposit insurance. Therefore, we do not conduct a specific welfare analysis. Still, a comparison to the results in Van den Heuvel (2008) is warranted. Van den Heuvel (2008) finds the welfare cost of capital adequacy regulations to be equivalent to a permanent reduction in aggregate consumption of between 0.1% and 1%. This relatively high cost is associated with the fact that capital regulations limit the ability of banks to create liquidity in an environment where households value liquidity services as well as consumption.[30] Our small financial accelerator effect (i.e., the effect of a TFP shock on households' consumption in Figure 4B is not significantly different from that in an economy where banks are not required to hold capital and finance loans only with debt), together with the fact that the returns on shares and on deposits (Figure 2B) and consumption (Figure 2C) stay constant after an increase in γ, could all be interpreted as a small welfare cost of bank capital. The main reason for the difference in conclusions in that unlike the case in Van den Heuvel (2008), in our setup agents do not explicitly value liquidity à la Sidrauski.

To conclude, our general equilibrium structural framework allows us to confirm the findings in the empirical literature of weak evidence for the "credit crunch" hypothesis. The advantage over empirical work is that our general equilibrium model is free from the criticisms made of existing empirical work, and it allows us to isolate the effects of capital regulations on the supply of bank credit.[31] Moreover, with a structural framework, this weak evidence is obtained endogenously in the model, so that it can be explained as a general equilibrium result. Therefore, we are able to fill the existing gap between the empirical and the theoretical literature.

A model with labor financing. As a robustness check, we also simulated a model where firms access credit markets to finance both investment and their working capital needs (i.e., $w_t h_t$).[32] The results of this exercise are presented in Appendix B.

Tables B.1 and B.2 and Figures B.1 and B.2 show that the qualitative results are the same as for the benchmark version of the model. Bank variables respond in the same way to a TFP shock, the financial accelerator is still present in the model, it is still rather weak, and macroeconomic variables still display more volatility than in a model with no capital adequacy regulations. Thus, we can conclude that our results are robust to the specification chosen for the financing constraint in equation (20).

This was an expected conclusion because the particular specification chosen for the financing constraint (investment financing, working capital needs, or any combination of them) will directly impact firms' demand for bank loans, but it will not affect the independent response of bank loan supply to a negative shock in bank equity (i.e., it will not impact the size of the financial accelerator). In our model, the negative impact of a TFP shock on bank equity operates via firms' profits, as described in equations (1)–(3). Combining these three equations, we obtain the following equation of motion for bank equity:

$$e_{t+1} = e_t - \Delta_t + (1-\tau)\left[i_t(D_t + e_t) + \pi_t^{\text{firm}} - r_t D_t\right].$$

There is no link in this equation to the specification of the financing constraint. Thus, an alternative specification does not significantly change our results.

4. CONCLUSIONS

The Basel Accords of 1988 set a benchmark for banks' solvency standards by stating that their capital should not fall below 8% of their risk-weighted portfolio of assets.

It has been hypothesized that these bank capital requirements produced a "credit crunch" that in turn exacerbated the recessions experienced by OECD countries in the early 1990s. However, the empirical literature provides little support for this idea. Moreover, being mostly based on partial equilibrium models, the existing theoretical literature cannot study this issue. We bridge this gap between empirics and theory by providing a general equilibrium theoretical foundation for the existing empirical work. The contribution of doing so is twofold: First, having a structural, theoretical model of the "credit crunch" allows us to isolate the effect of capital requirements on bank lending, addressing the concerns raised by previous empirical work. Second, our framework allows us to study the financial accelerator effect of capital requirements.

The main insight we obtain from our general equilibrium analysis is that bank capital requirements do cause a "credit crunch," acting as a financial accelerator, albeit a small one. Thus, using a framework that is free from the criticisms faced by the empirical work, we are able to confirm their finding that there is weak evidence for the "credit crunch" hypothesis, and to provide a theoretical explanation for this result.

A stronger financial accelerator may be obtained with some modifications of the assumptions made in our framework. An oligopolistic market structure would make bank profits depend on the demand for bank credit. This could yield a more persistent financial accelerator, as the dynamics of bank profits and thus bank equity would be now determined by the TFP process. Modeling economies of scale in the intermediation services of banks would also enhance the financial accelerator. Also, introducing bank assets of maturity longer than one period would increase the persistence of the financial accelerator.

Other relevant extensions would likely decrease the importance of the financial accelerator. Introducing bank heterogeneity in degree of capitalization would break the rigid link between bank capital and aggregate lending.[33] Also, the effects of the regulation would likely be weaker if the model accounted for the alternative strategies used by banks (such as securitization of their riskier assets) to overcome the capital requirements and to "artificially" increase their capital-to-assets ratio.

Another worthwhile extension would be to analyze whether the one-sided constraints on bank capital imposed by the regulation may result in asymmetric business cycles with respect to a positive and a negative TFP shock. Another extension would be to introduce endogenous credit risk into the model and to study the potential procyclical effects of capital regulation in this setup. Last, we could feed the model with interest rate shocks to study monetary policy issues in the context of bank capital regulations.

Finally, an important and very timely issue is the link between capital requirements and aggregate risk. Should fixed requirements be strictly enforced in an environment of high aggregate risk (such as a wave of failures in the production sector or a stock market crash) that causes a generalized undercapitalization of banks? It would be interesting to explore this link in light of the Basel II guidelines. In Basel II the risk weights used to calculate capital-to-assets ratios are variable, derived from banks' own credit-risk models, as opposed to the fixed risk weights set by the Accords under Basel I. Kashyap and Stein (2004) argue that with default risk increasing during recessions, Basel II will result in procyclical capital-to-assets ratios and countercyclical capital charges (i.e., countercyclical recapitalization needs). If banks cannot all recapitalize at the same time, a reduction in bank credit will occur. In such a context the imposition of capital requirements may have consequences for the rest of the economy, if the reduction in bank credit effectively impacts investment and production for bank-dependent firms.[34] Therefore, it could be expected that the mild financial accelerator effects we obtain here for the Basel I framework may become significantly stronger under Basel II. However, our simulations from a model with fixed risk weights indicate that it might happen that forward-looking banks will anticipate that recapitalization needs increase during downturns, and to avoid hitting the regulatory constraint they will hold more excess capital than under Basel I. Consequently, it is not necessarily true that the financial accelerator will be stronger under the new regulatory framework. Studying the properties of our model augmented with variable (pro or countercyclical) required ratios is left for future work.[35]

NOTES

1. The guidelines for banking regulation and supervision in the Basel Accords of 1988 require bank to observe a minimum ratio of their accounting capital to the risk-weighted sum of their assets. The Basel Accords set this capital requirement at 8%, which for several countries was significantly higher than the minimum required at the time [Basle Committee [BIS] (1999)].
2. They find a significant effect only for banks with low regulatory ratings.
3. They find evidence only for internationally operating banks.
4. First, there is an identification concern. Because the coefficients are inferred from changes in market equilibrium quantities, the negative shocks to bank lending could be the result of declines in the demand for loans. Second, most of these studies implicitly assume that correlation means causality. It may be true that a decline in bank capital makes banks cut back on lending, but it is also possible that periods during which bank lending is low coincide with those when banks make large write-offs and special provisions that reduce bank capital [Peek and Rosengren (1995b)].
5. There are a few exceptions. Chen (2001) and Meh and Moran (2008) develop general equilibrium models. However, they focus on the effects of market capital requirements, and they cannot address the question of whether capital adequacy regulations can cause a "credit crunch."
6. Another related strand of the literature is given by Chami and Cosimano (2001), Tanaka (2002), Sunirand (2003), Bolton and Freixas (2006), Markovic (2006), and van den Heuvel (2007), among others. They focus on the implications of capital adequacy regulations for monetary policy.
7. Only Blum and Hellwig (1995) have previously carried out a formal analysis of this hypothesis in a general equilibrium setting. However, theirs is a static AD-AS model with no micro-foundations and therefore with some shortcomings for an assessment of the accelerator. In particular, their model cannot explain how the optimal profit-maximizing capital-to-assets ratio chosen by banks changes endogenously over the business cycle, occasionally hitting the constraint imposed by the regulation.
8. A recent working paper by Devereux and Yetman (2010) develops a model of the international transmission of shocks due to interdependent portfolio holdings among financial institutions subject to a capital adequacy regulation.
9. To our knowledge, the earliest model of banking in general equilibrium is Bernanke and Gertler (1987).
10. Flannery and Rangan (2004) provide empirical evidence that bank capital holdings have significantly increased since 1994, exceeding the regulatory minimum. They also document that after the second half of the 1990s this increase is explained mainly by a prominent influence of market forces (higher risk aversion of banks' counterparties combined with an increase in the risk of banks' asset portfolios) on bank leverage decisions. Thus, they show that the increased capital holdings are not only the result of increased supervisory pressure on book capital ratios (i.e., higher costs of not meeting capital adequacy regulations), increased retained earnings, or a valuation effect derived from the stock market appreciation of the 1990s.
11. Aiyagari and Gertler (1998) use a dynamic model to explain why asset prices in stock markets tend to decrease below their fundamental values. This is an augmented Lucas–Tree model that includes a trader firm that uses leverage plus equity to finance investments in risky securities. However, this trader firm is limited in the amount of debt it can use. A key assumption in their model is that issuing equity is not a possibility for the traders (or banks) and thus the best way they can recapitalize after an adverse shock is through retained earnings (i.e., reducing dividend payments to their owners).

Moreover, because there is no benefit from using leverage in their model, they obtain the result that the trader (or bank) resorts to an all-equity financing strategy. In order to avoid this unrealistic long-run prediction, they suggest the introduction of some kind of benefit from holding debt (or bank deposits).

12. Van den Heuvel (2007) focuses on the role of capital requirements in the transmission of monetary policy, as opposed to the business cycle amplification role. This is a partial equilibrium analysis, but still incorporates some elements absent in our work (e.g., an imperfect market for bank equity and a maturity transformation that exposes banks to interest rate risk).

13. The representative bank's objective can be derived from first principles by solving forward the pricing equation for bank shares derived in the households problem. From the FOCs for the households problem it can be shown that, the price of bank shares is determined by the expected gross rate of return on shares discounted at the households' intertemporal marginal rate of substitution.

14. This is a sensible assumption, because banks are likely to be concerned about the inferences that depositors can draw as regards their solvency when they issue shares in the face of a negative shock. Explicitly modeling issuance of shares is beyond the scope of this study. For simplicity we normalize $\bar{s}$ to 1.

15. This inequality constraint is also responsible for turning the bank's problem into a dynamic one. If there were no capital regulation, banks would prefer to hold no equity (due to the tax exemption on interest payments on deposits). And, from the equation of motion for bank equity, it is clear that the only intertemporal problem for the bank is the choice between dividend payments and retained earnings. This explains why in spite of this being a dynamic optimization problem, there are no laws of motions for loans and deposits. As regards deposits and loans, the competitive bank will intermediate all the funds needed at the ongoing market interest rate.

16. The fact that the supply of bank shares is inelastic allows the bank to transfer the full amount of the tax to stockholders.

17. It can be shown that the system in equations (18)–(20) reduces to $\pi_t^{\text{firm}} = A_t F(K_t, l_t) - w_t l_t - (\delta + i_t)K_t$, where the term $(\delta + i_t)$ represents the user's cost of capital. This shows that π_t^{firm} can become negative as a result of an adverse TFP shock. Because with the financial contract we specify in this model both K_t and i_t are state variables, a negative shock in period t, if large enough, can cause revenues to fall below total costs.

18. Equation (20) is also a balance sheet condition that states that the firm's assets (i.e., capital stock) equal its liabilities (i.e., outstanding bank loans). According to this specification, the creditors (i.e., the banks) are the only claim holders to the firm's assets. Thus, this constraint rationalizes the assumption that firms' profits are received by the bank.

19. Allowing for firm equity would imply adding an additional state variable to a model that already has six state variables and two occasionally binding constraints, affecting the numerical tractability of the DSGE model.

20. In equilibrium, aggregate state variables coincide with their individual counterparts.

21. Aiyagari and McGrattan (1998) and Ljungqvist and Sargent (2000) analyze the issue of self-insurance for households, when they are subject to borrowing constraints in the context of idiosyncratic uncertainty and incomplete asset markets.

22. One would expect that all else equal, risk-weighted assets in a developed country (i.e., a country with the current parameterization of the TFP process) fall below total assets, so that the ratio using risk-weighted assets is higher.

23. The numerical method we use allows us to conduct this kind of exercise, which would not be implementable by other methods.

24. By the bank's balance sheet constraint, according to which $(e + D) = L$.

25. See the Introduction for a detailed discussion.

26. As explained before, the spread increases as the regulatory constraint starts to bind. Therefore, the cost of credit increases even with the interest rate on deposits falling.

27. Firms' profits fall if the negative shock is large enough to make current earnings fall below the cost of labor and the cost of repaying the loans for which terms were contracted in the previous period. This is related to the fact that both K_t and i_t are state variables in our model. Therefore, by equation

(23), after a shock in period t, $(\delta + i_t)K_t$ can end up being different from $A_t F'_{K_t}$, so that even with $A_t F'_{l_t} = w_t l_t$, π_t^{firm} might be different from zero. A negative enough TFP shock can make profits become negative.

28. The countercyclical interest rate spread is in line with recent empirical evidence by Aliaga-Díaz and Olivero (2010) and Olivero (2010).

29. The models in Bernanke and Gertler (1989) and Carlstrom and Fuerst (1997) are "principal–agent" models where borrowers' net worth acts as a source of output dynamics. The reason is that net worth is inversely related to the agency cost and the external finance premium of financing real capital investment. As a result, in this framework agency costs enhance the propagation of aggregate productivity shocks. Bernanke et al. (1996) use firm-level data to provide empirical evidence on the BG financial accelerator. They document that in bad times credit flows away from borrowers more subject to agency costs, a pattern consistent with the financial accelerator. The theory of the accelerator predicts a differential effect of an economic downturn on borrowers who are subject to more severe agency problems in credit markets and borrowers who do not face serious agency problems; the difference arises because declines in net worth raise the agency costs of lending to the former but not the latter. Therefore, if the financial accelerator is operative, at the onset of a recession we should see a decline in the share of credit flowing to those borrowers more subject to agency costs (a "flight to quality" in credit extension) [Bernanke et al. (1996)].

30. Diamond and Rajan (2000) and Gorton and Winton (2000) also show that capital requirements can have important social costs.

31. See the Introduction for details.

32. Notice, though, that the constraint $K_t = L_t$ can be seen also as the firm's balance sheet, with firm's assets equal to firm's liabilities and with no firm equity. According to this specification, the creditors (i.e., the banks) are the only claim holders to the firm's assets. Thus, this constraint rationalizes the assumption that firms' profits are received by the bank. With wage financing, this link between the financing constraint and the firm's balance sheet is broken, so that banks would no longer be the only claim holders to the firm's assets, and the assumption of banks receiving π_t^{firms} would become more arbitrary.

33. As firms switch from poorly capitalized banks to healthier banks during recessions, bank lending and investment fall by less than in the representative bank model.

34. For this result to materialize banks must find it difficult to recapitalize, and it has to be costly for firms in the goods markets to replace bank loans with other forms of financing. According to Blum and Hellwig (1995), these two conditions are easily met. First, banks in general are reluctant to issue equity during bad times because of the negative inferences that may be drawn as regards their solvency. Second, firms use predominantly bank lending. In the United States around 60% of external financing is represented by bank loans, whereas the rest is bonds and stocks. Moreover, approximately half of the bonds and almost all of the stock are sold to some kind of financial intermediary [Dewatripont and Tirole (1994)].

35. For recent work on the Basel II Accords, see Catarineu-Rabell et al. (2005), Gordy and Howells (2006), Zicchino (2006), Saurina and Trucharte (2007), and Repullo and Suárez (2008), among others.

36. It would be necessary to iterate over the Bellman equation for each agent in the economy, taking prices as given, and then check whether markets clear at those prices. If they do not, the algorithm should update prices and then solve all over again. See Mendoza and Smith (2002) for an application of value function iteration with occasionally binding constraints in a decentralized economy setting.

37. First, to evaluate the fit of a candidate approximation, the PEA method relies on running Monte Carlo simulations of the dynamic path, and then computing the Euler equation errors along the simulated path. With the Monte Carlo approach introducing some errors, long simulations must be run, substantially reducing the efficiency of the algorithm. Long simulations of the dynamic path can be problematic when the dynamic system is not highly stationary. In that case the estimation of parameters by nonlinear least squares [as suggested in Marcet and Lorenzoni (1999)] could result in inconsistent parameter estimates. Second, the convergence properties of this method are unknown.

According to Judd (1991), there is no reason to prefer the PEA over available algorithms for solving nonlinear equations that are quadratic in convergence. Moreover, Judd (1991) explains that PEA often has explosive oscillations, particularly as one attempts to use more flexible approximations. Finally, in our model the inequality constraints introduce kinks into the functions being approximated, and this makes the approximation more difficult.

38. It has been shown that expectation operators can be approximated well by a discrete distribution [see Miranda and Fackler (2002) and Burnside (1999)].

39. These are functions of the form $\phi(\Upsilon)\theta$, where Υ represents the state space, $\phi(\Upsilon)$ is a vector of basis functions' and θ is a matrix of coefficients.

40. The system would be n^m equations in n^m unknowns for a state space of dimension m, and it would increase to $p \times n^m$ with p response functions being approximated. However, with linear splines and making the breakpoints of the spline coincide with the collocation nodes, the actual number of coefficients to compute falls to $p \times n \times m$.

41. Normally, the initial values are chosen by fitting the basis functions to the solution from a log-linear approximation around the deterministic steady state, ignoring the occasionally binding constraints in the linearization. This strategy is not helpful in our case because the deterministic steady state implies a corner solution for the optimal capital-to-assets ratio of the bank, with the regulation constraint always binding. With no interior solution for the expansion point, we cannot simply ignore the constraints. An alternative would be to assume that these constraints are always binding. However, using the policy functions resulting from this assumption as starting values would be very misleading because we expect a radically different behavior for banks over the true stochastic steady state, where an interior optimal capital-to-assets ratio is the most likely state of nature.

42. It is worth noting that although good starting values for the coefficients are important for raising the probability of convergence to the true solution, they are neither a necessary nor a sufficient condition for convergence.

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APPENDIX A: DATA

TABLE A.1. Bank capital holdings: Ratio of bank equity to total assets (weighted by total assets)

	Mean	Std. dev.	Min	Max
Argentina	0.1034	0.0127	0.0855	0.1241
Australia	0.0682	0.0066	0.0508	0.0741
Austria	0.0425	0.0039	0.0356	0.0472
Belarus	0.1868	0.1139	0.0243	0.3643
Belgium	0.0336	0.0040	0.0287	0.0419
Bolivia	0.0973	0.0162	0.0670	0.1159
Botswana	0.0733	0.0109	0.0509	0.0893
Bulgaria	0.1497	0.0351	0.1001	0.1957
Canada	0.0927	0.0100	0.0781	0.1086
Chile	0.0883	0.0029	0.0836	0.0934
China	0.0485	0.0087	0.0322	0.0594
Colombia	0.1140	0.0095	0.1013	0.1340
Costa Rica	0.1102	0.0108	0.0819	0.1200
Croatia	0.1016	0.0142	0.0836	0.1264
Cyprus	0.1114	0.0246	0.0515	0.1412
Czech Republic	0.0727	0.0088	0.0554	0.0840
Estonia	0.1295	0.0354	0.0802	0.1657
Finland	0.0732	0.0224	0.0482	0.1027
France	0.0376	0.0049	0.0300	0.0454
Georgia	0.2146	0.0572	0.1270	0.2973
Germany	0.0364	0.0048	0.0299	0.0418
Greece	0.0776	0.0200	0.0506	0.1098
Hong Kong	0.0927	0.0109	0.0723	0.1118
Hungary	0.0877	0.0097	0.0769	0.1028
Iceland	0.0672	0.0076	0.0591	0.0807
Indonesia	0.0790	0.0258	0.0287	0.1097
Israel	0.0629	0.0041	0.0577	0.0691
Italy	0.0725	0.0098	0.0613	0.0980
Japan	0.0418	0.0074	0.0282	0.0513
Jordan	0.0903	0.0294	0.0656	0.1632
Korea	0.0497	0.0087	0.0401	0.0661
Kyrgyz Republic	0.1630	0.0550	0.0791	0.2448

TABLE A.1. (Continued.)

	Mean	Std. dev.	Min	Max
Latvia	0.0930	0.0136	0.0811	0.1275
Lithuania	0.1014	0.0192	0.0749	0.1335
Malaysia	0.0839	0.0054	0.0741	0.0894
Malta	0.0921	0.0266	0.0518	0.1307
Mauritius	0.1137	0.0130	0.0952	0.1378
Mexico	0.1013	0.0143	0.0811	0.1293
Morocco	0.0885	0.0082	0.0740	0.1016
Netherlands	0.1014	0.0141	0.0746	0.1225
New Zealand	0.0428	0.0114	0.0335	0.0661
Norway	0.0627	0.0045	0.0559	0.0693
Peru	0.0968	0.0082	0.0816	0.1078
Philippines	0.1341	0.0134	0.1164	0.1590
Poland	0.1061	0.0072	0.0984	0.1212
Portugal	0.0735	0.0190	0.0543	0.1151
Romania	0.1340	0.0322	0.0816	0.1754
Singapore	0.1077	0.0202	0.0572	0.1247
Slovak Republic	0.0774	0.0218	0.0356	0.1029
South Africa	0.0784	0.0143	0.0645	0.0997
Spain	0.0650	0.0090	0.0535	0.0822
Sweden	0.0363	0.0030	0.0313	0.0413
Switzerland	0.0451	0.0046	0.0378	0.0512
Thailand	0.0660	0.0141	0.0479	0.0870
UK	0.0511	0.0111	0.0310	0.0611
US	0.0802	0.0138	0.0603	0.1023

Source: Bank-level data from Bankscope and the Call Reports on Condition and Income for the United States. Period is 1997–2006 for all countries except for the United States for which it is 1984–2008.

TABLE A.2. Bank capital holdings: Bank regulatory capital to risk-weighted Assets (in %)

	2003	2004	2005	2006	2007	2008
Latin America	15.7	15.9	15.6	15.1	14.5	14.6
Emerging Europe	19.5	18.7	17.2	16.0	15.4	15.3
Western Europe	12.9	13.2	12.9	12.8	12.3	12.7
Asia	12.6	12.3	13.0	13.2	13.0	13.5
Middle East and Central Asia	18.1	18.2	18.7	20.1	17.5	15.8
Sub-Saharan Africa	15.1	18.2	17.9	17.6	18.0	18.7
Australia	10.0	10.4	10.4	10.4	10.2	10.9
Canada	13.4	13.3	12.9	12.5	12.1	12.7
Japan	11.1	11.6	12.2	13.1	12.3	12.4
United States	13.0	13.2	12.9	13.0	12.8	12.8

Source: IMF Global Financial Stability Report: Navigating the Financial Challenges Ahead, October 2009.

APPENDIX B: ROBUSTNESS CHECK

In this appendix we present the results of a robustness check performed on the model by allowing firms to also finance their working capital needs using bank credit. Tables B.1 and B.2 present the results of the simulation analysis. Figures B.1 and B.2 present the impulse responses to a negative TFP shock for bank and macroeconomic variables, respectively.

TABLE B.1. Simulation moments: Macroeconomic variables

	Regulated economy $\gamma = 0.08$	Unregulated economy $\gamma = 0$
	Means ($\mu(x)$)	
TFP (A)	1.0002	1.0000
Capital (K_{t+1})	3.5274	3.5812
Consumption (C_t)	1.1752	1.1799
Labor (l_t)	1.0110	1.0142
Wages (w_t)	1.0121	1.0156
Investment (I_t)	0.3527	0.3581
Output (Y_t)	1.5275	1.5382
	St. dev. ($\sigma(x)$)	
TFP (A)	0.0165	0.0165
Capital (K_{t+1})	0.1499	0.1438
Consumption (C_t)	0.0362	0.0357
Labor (l_t)	0.0182	0.0178
Wages (w_t)	0.0200	0.0196
Investment (I_t)	0.0229	0.0222
Output (Y_t)	0.0575	0.0566
	St. dev. relative to output ($\frac{\sigma(x)}{\sigma(Y)}$)	
TFP (A)	0.2875	0.2922
Capital (K_{t+1})	2.6062	2.5421
Consumption (C_t)	0.6300	0.6313
Labor (l_t)	0.3159	0.3140
Wages (w_t)	0.3478	0.3459
Investment (I_t)	0.3980	0.3923
	Correlations with GDP ($\rho(x, Y)$)	
TFP (A)	0.8652	0.8758
Capital (K_{t+1})	0.8030	0.7933
Consumption (C_t)	0.9839	0.9856
Labor (l_t)	0.9999	0.9999
Wages (w_t)	0.9999	0.9999
Investment (I_t)	0.9607	0.9627

TABLE B.2. Simulation moments: Bank variables

	Regulated economy $\gamma = 0.08$	Unregulated economy $\gamma = 0$
Means ($\mu(x)$)		
Equity (e_{t+1})	0.3318	—
Deposits (D_{t+1})	3.1955	—
Gross interest rate on deposits ($1 + r_{t+1}$)	1.0428	1.0419
Spread ($i_{t+1} - r_{t+1}$)	0.0002	—
Dividends (Δ_t)	0.0128	—
St. dev. ($\sigma(x)$)		
Equity (e_{t+1})	0.0156	—
Deposits (D_{t+1})	0.1363	—
Gross interest rate on deposits ($1 + r_{t+1}$)	0.0031	0.0028
Spread ($i_{t+1} - r_{t+1}$)	0.0005	—
Dividends (Δ_t)	0.0014	—
St. dev. relative to output ($\frac{\sigma(x)}{\sigma(Y)}$)		
Equity (e_{t+1})	0.2705	—
Deposits (D_{t+1})	2.3705	—
Gross interest rate on deposits ($1 + r_{t+1}$)	0.0545	0.0498
Spread ($i_{t+1} - r_{t+1}$)	0.0085	—
Dividends (Δ_t)	0.0239	—
Correlations with GDP ($\rho(x, Y)$)		
Equity (e_{t+1})	0.9019	—
Deposits (D_{t+1})	0.7798	—
Gross interest rate on deposits ($1 + r_{t+1}$)	−0.0398	−0.0430
Spread ($i_{t+1} - r_{t+1}$)	−0.4501	—
Dividends (Δ_t)	0.8865	—

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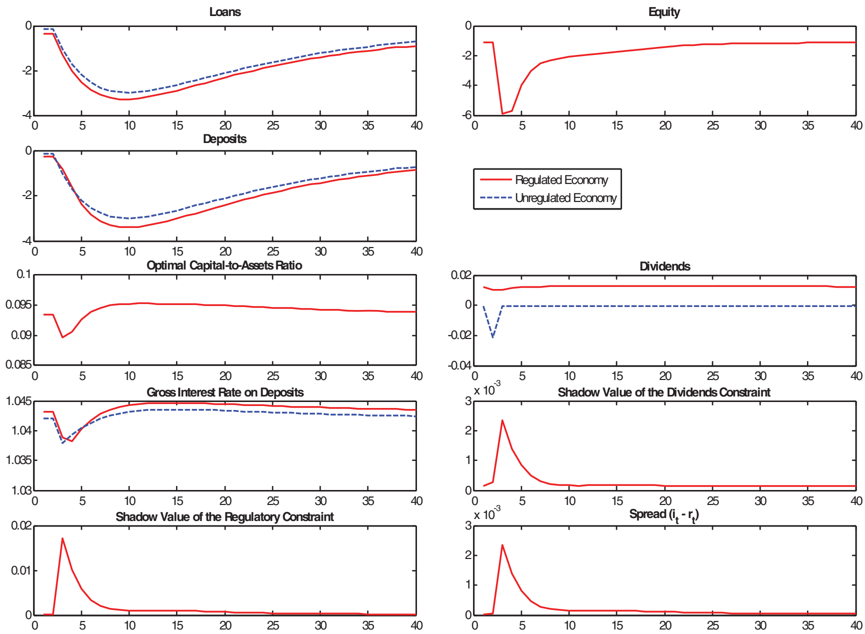

FIGURE B.1. Impulse-response functions to a −2.5% TFP shock—investment and labor financing—bank variables. Values on the vertical axes are percentage deviations with respect to the steady state for loans, equity, and deposits. They are levels for all other variables.

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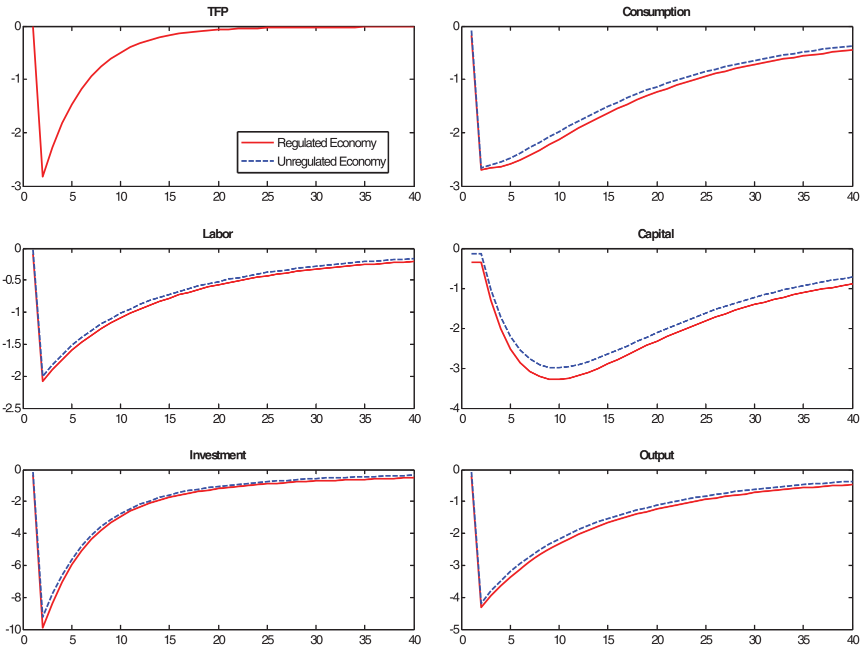

FIGURE B.2. Impulse-response functions to a −2.5% TFP shock—investment and labor financing—macroeconomic variables. Values in the vertical axes are percentage deviations with respect to the steady state.

APPENDIX C: NUMERICAL METHOD

Our model cannot be formulated in terms of a central planner's problem. Therefore, using methods such as value function iteration or policy function iteration in this decentralized competitive environment is not practical because solving for market clearing prices adds an extra loop to the algorithm.[36] Moreover, due to the occasionally binding nature of the regulation constraint and the nonnegativity constraint on dividends, perturbation methods are not appropriate to numerically approximate the model's solution. The parameterized expectations approach (PEA) would have been another alternative. However, there are a number of disadvantages of this method as compared to the more general class of minimum weighted residual methods [see Judd (1991)].[37]

With these considerations in mind, in this paper we use a weighted residual method of the finite-element type. The general idea in weighted residual methods [see Judd (1991) and McGrattan (1999)] is to represent the approximate solution to the functional equation problem with a linear combination of known basis functions (such as polynomials). The method consists of finding the coefficients of the combination that minimize an appropriately defined residual function evaluated at the approximate solution. The finite-element method can be understood as a piecewise application of the weighted residual method. That is, the domain of the state space is divided into nonoverlapping subdomains, and low-order

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polynomials are fitted to each of them. The local approximations are then pieced together to give the global approximation.

We use several utilities included in the `CompEcon` toolbox by Fackler and Miranda (2002). We take the following steps to solve the model based on Fackler (2005).

First, denoting by e the random variable and w_j the probabilities associated to each realization e_j of e, the idea is to approximate numerically the integral involved in the expectation.[38] That is, the idea is to assume $E[f(e)] \approx \sum_j w_j f(e_j)$. Here we use a five-point Gaussian quadrature approach for this approximation.

Second, the optimal policy functions of unknown form must be approximated numerically. The optimal policies are a function of the state variables both directly and indirectly through the conditional expectation function (which is also of unknown form). Thus, there are two possibilities: one can directly approximate the policy functions or one can first approximate numerically the expectations as a function of the states and then solve for the optimal policy from the equilibrium conditions.

Here we use piecewise linear functions as the approximant functions.[39] This basis tends to give a better approximation when there are kinks in the approximate solutions such as those corresponding to inequality constraints.

Third, once the approximant functions have been selected, one needs to choose a criterion to determine the weights of the basis functions given by the matrix of coefficients. With this goal we use the collocation method of Miranda and Fackler (2002). The idea is to partition the state space at n points, called the collocation nodes. The coefficients are found by requiring the approximant to make an appropriately defined residual function equal to zero at those nodes. Because the approximant consists of n basis functions and n coefficients, the collocation method amounts to replace the infinite-dimensional functional equation problem with a system of n nonlinear equations.[40] We then use standard algorithms (such as the Newton method or the more efficient quasi-Newton method called the Broyden method) to solve for the coefficient values.

Due to the curse of dimensionality, we need a fixed-point iteration to solve our model. The iteration starts with some guess on the parameter values and it computes optimal policies for the next period for each and every state of nature using the states transition rule. With these next period policies and the shocks, the integral corresponding to the expectation function is approximated numerically. Once the values of the expectation functions are known, the optimal policies are recomputed and the initial guess is updated. The iteration continues until the change in the policies or the parameters is sufficiently small.

Next, we discuss some considerations in the numerical solution that are specific to our model.

C.1. DISCRETIZATION OF THE STATE SPACE

For the implementation of the numerical solution, we use the representative bank's balance sheet to express the model in terms of e_t and D_t only (i.e., eliminating L_t). Because both loans and deposits are risk-free, the gross interest rate on deposits $(1 + r_t)$ and the interest rate spread $\text{spread}_t \equiv (i_t - r_t)$ are state variables. The state space $\Upsilon = [e_t, D_t, (1 + r_t), \text{spread}_t, Z_t, A_t]$ is therefore of dimension $m = 6$.

The high dimensionality of the state space imposes restrictions on the number of grid points that can be introduced in each dimension. This in turn reduces the quality of the approximation. In this sense, a lot can be gained if the policy functions exhibit a moderate

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degree of curvature (other than the kink corresponding to the regulation constraint) and a linear spline basis is used. To improve the quality of the approximation we spread the breakpoints unevenly over the domain, concentrating them more in the region where the kink is most likely to lie. We concentrated the points more heavily at low values of e_t and A_t and at high values of D_t, because both the regulation constraint and the nonnegativity constraint on dividends are more likely to bind when bank equity is relatively low (or when bank deposits are relatively high) and during recessions. The vector of grid points along each dimension is given by

$$\mathbf{e} = e_{\min} + \left[0, \frac{1}{6}, \frac{1}{3}, \frac{1}{2}, \frac{3}{4}, 1\right](e_{\max} - e_{\min}),$$

$$\mathbf{D} = D_{\min} + \left[0, \frac{1}{4}, \frac{1}{2}, \frac{2}{3}, \frac{5}{6}, 1\right](D_{\max} - D_{\min}),$$

$$\mathbf{A} = A_{\min} + \left[0, \frac{1}{6}, \frac{1}{3}, \frac{1}{2}, \frac{3}{4}, 1\right](A_{\max} - A_{\min}),$$

$$\mathbf{x} = \{(\mathbf{1}+\mathbf{r}), \mathbf{spread}, \mathbf{Z}\} \rightarrow 4 \text{ evenly spaced points in } \quad [x_{\min}; x_{\max}].$$

C.2. CHOICE OF STARTING VALUES

We choose the initial values of the coefficients by fitting the basis functions to the solution from a log-linear approximation around the deterministic steady state of a model where the two inequality constraints are substituted by smooth penalty functions. If the penalty functions have a high enough degree of curvature, the resulting decision rules mimic fairly well the optimal behavior of agents with occasionally binding constraints. Thus, this technique provides a very good informed guess of the true decision rules.[41,42]